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PLEISTOCENE GEOLOGY OF THE SAWATCH RANGE, NEAR LEADVILLE, COLO.

THE writers, as students of geology in the University of Chicago, spent two months of the past summer in studying the glacial geology about Leadville, Colo. It is their plan to continue the work next summer. The work was carried on under the direction of Professor R. D. Salisbury, who was with the writers for a week toward the close of the season's work.

So far as known, little detailed work on the Pleistocene geology of the region had been done. The maps of the Hayden Survey mark certain areas as being morainic, and Mr. S. F. Emmons, in his monograph,[1] mentions briefly the effects of glaciation in this area; but otherwise little seems to have been published.

The work of the past summer was mainly on the east slope of the Sawatch Range. It covered all the area on the Leadville quadrangle of the U. S. Geological Survey, which lay to the west of the Arkansas River, the Tennessee Fork, and the Eagle River.

TOPOGRAPHY

The chief topographic features of the region are the two great parallel north-south mountain ranges, the Sawatch Range on the west, and the Park Range on the east. The higher peaks of both rise to heights of more than 14,000 feet. In the trough between these ranges are the Arkansas and Eagle Rivers. The former flows south, and the latter north. These rivers are fed by large numbers of tributaries from the slopes to the east and west, most of the tributary valleys being almost at right angles to the valley of the main stream.

GLACIATION

The area studied is about 350 square miles in extent. Of this, 275 square miles show definite effects of glaciation. It is probable that, at the maximum, the ice covered a somewhat larger area. The drift is referable to at least two distinct epochs of markedly different age, with possibilities of a third epoch much earlier than the two whose results are well marked.

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[1] *Monograph XV*, U. S. Geological Survey, pp. 41–44.

EXTENT OF ICE

The last glacial epoch.—The ice of the last glacial epoch covers by far the larger part of the surface of the mountains proper. The ice came down all the larger valleys tributary to the main valley, and in most cases only the narrow crests of the ridges between the side valleys projected above the glaciers. In several instances the glaciers of the side valleys descended to the present position of the river in the main valley, and in a few cases they crossed the main valley to the base of the opposing range. Of the entire area west of the great north and south valley about three-fourths was covered by the ice of the last glacial epoch, and a large part of the unglaciated one-fourth lies beyond the foot of the mountains proper.

Ten distinct systems of glaciers of some importance were studied in this area, besides four cliff glaciers of small size. Of the ten more important systems three extended barely to the foot of the mountains. Seven got well out into the wide valley, east of the mountains, and five of them extended to the present position of the river, and the same number extended below the 9,000-foot contour.

The glaciers varied in length from one to twenty miles, and in area from one-third of a square mile to about eighty square miles. The Lake Creek system was longest, and also greatest in area. Of the very small glaciers, one started at an elevation of 11,000 feet, but an elevation of about 12,000 feet seems to have been necessary to start glaciation in most places. The glaciers all originated in similar situations. Their sources were in cirques which lay back toward the higher parts of the mountains. The ice from these cirques, moving downward, merged in each of the principal mountain valleys, and developed a tongue of ice which advanced far down the valleys. About sixty separate cirques contributed to the ten large glaciers of the region.

In all the larger glaciers the ice had a thickness of over 1,000 feet, while in the valleys of Homestake and Roche Moutonnée Creeks the thickness exceeded 2,000 feet.

The drift.—The character of the glacial deposits varies greatly in topographic form and physical constitution, with the character of the surface upon which the deposits were laid down, and with the material which the ice had to handle. In the Evergreen Lakes glacier, for example, the drift has a characteristically new appearance, both in respect to its materials and its topography. The material of the drift of the Lake Fork glacier, on the other hand, looks very old. There are few large bowlders at the surface, and most of the rock material in the drift is notably decayed. But the topography of even this moraine is new, and it was, without question, contemporaneous with the newer appearing drift of the Evergreen Lakes moraines.

The difference in the material in these two cases is to be explained by the difference in the condition of the rocks over which the two glaciers moved. Even now the bed-rock in the upper part of the valley of Lake Fork is deeply decayed, showing that the glacier did not clean out even all the decayed rock. The upper part of the area out of which the Evergreen Lakes glacier moved is of hard fresh rock, showing that the ice of the glacier removed not only all decayed rock, but also some of the fresh rock beneath. The freshness of the drift deposited by this glacier shows that much undecayed rock was worn away by the ice.

The glaciers terminated in two classes of situations, and their terminal deposits stand in a somewhat definite relation to the position of the ends of the glacier. The ice in the valleys of Homestake and Rock Creeks, and in the valley west of Mitchell, never reached a Piedmont plain upon which they could deploy, but ended in the narrow mountain valleys. Under these conditions there was no opportunity for the terminal deposits to accumulate in great terminal moraines, since the abundant water from the melting ice carried the drift away about as fast as the ice left it. No terminal moraines of consequence occur at the ends of these glaciers.

The other larger glaciers of this region sent their ice beyond the confines of the narrow valleys, and deployed to some extent on the valley plain beyond, building great terminal moraines. These two types of termini and of terminal accumulations are well shown by the glaciers of Homestake Creek, on the one hand, and those of Lake Fork, Clear Creek, and Half Moon Creek, on the other. The absence of terminal moraines in the former case has been noted. In glaciers of the Lake Fork type, the ice deployed on the plain at the base of the mountains, and enormous quantities of drift were piled up in the form of terminal moraines. The terminal moraines often have abrupt outer faces, 200 to 300 feet high, and are marked by a characteristically irregular, hummocky topography.

The terminal moraines are continuous with and merge into the lateral moraines in the mountain valleys. The lateral moraines are often large and lie against the valley walls, their crests sloping down the valley. The crests of the lateral moraines are over 700 feet above the stream in some parts of the valley of Clear Creek, and descend with an even slope of 200 to 400 feet a mile down the valley. Beyond the mountains, the lateral moraines tend to flatten out, and merge into extensive terminal moraines.

Little detailed work was done on the glaciation of the Park Range, but it is known that ice of the last glacial epoch occurred in the "gulches" east and southeast of Leadville; in the valleys of the East Fork of the Arkansas River, Ten-mile Creek, and over a considerable portion of the east slope of the Park Range.

The older drift.—In a number of places within the area studied there are tracts covered with scattered bowlders or bodies of drift, which are certainly of glacial origin, but which are much older than the drift of the last ice epoch. In these patches the present topography is due to erosion, all signs of kettles, or irregular hummocks, having disappeared. The rock outcrops have generally been weathered into sharp crags, a change which certainly required much more time than has elapsed since the last glacial epoch. The surface bowlders, too, are often weathered considerably, crumbling to pieces under the hammer.

The evidence that this drift is glacial is found along several lines. The bowlders are of a size which would militate against a fluvial origin. Striæ are sometimes found on the under, unweathered surfaces of the bowlders, or on the faces of those in fresh cuts in the drift. The distribution is such as would be expected from older and more extensive glaciers, for the drift in question occurs just outside the new drift, or above it on benches to which the last ice did not reach. The patchiness of the old drift is due largely to erosion since its deposition. In one or two instances the older drift shows something of the lateral moraine ridge form, outside and above the newer lateral moraines, but more often it occurs in thin sheets, or merely as scattered bowlders.

Possibility of a still earlier epoch of glaciation.—Certain facts point to the possibility of a still earlier epoch of glaciation in this region. Two miles above Granite, on the east side of the Arkansas River, bowlders were found 200 feet above the river, which seem to have come from the Sawatch Mountains. These bowlders are rather rare, and are much weathered, although of very resistant granite.[1] The position of these bowlders beyond the limits of the ice of both well-determined epochs of glaciation points to a possible period of glaciation older than either, the drift of which has been almost entirely removed. The evidence, however, does not seem to be altogether conclusive. Some other bits of evidence of like import are found at other points, but they have not been sufficiently developed to make their significance certain.

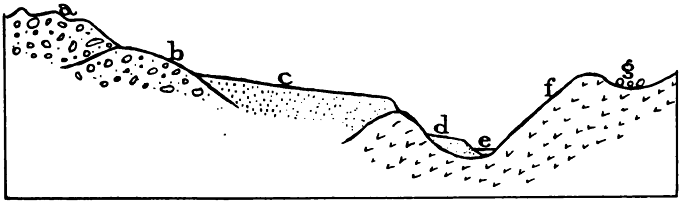

FIG. 1.—A generalized section across the valley of the Arkansas, to illustrate the conditions in the vicinity of Granite.

a, terminal moraine of last epoch from a side valley; *b*, moraine of older drift; *c*, high terrace lying against older drift; *d*, low terrace corresponding in age to *a*; *e*, Arkansas River; *f*, granite into which river has cut a post-older glacial channel; *g*, bowlders from mountains on opposite side of valley, which appear to be older than *b*.

The general relations of the two sheets of drift to each other, and of both to the valley gravels, and to the scattered bowlders of still greater age, are shown in Fig. 1.

TERRACES

High terraces.—A most striking feature of this region is the great display of terraces, seen at their best on the east side of the Arkansas River, south of Leadville. These terraces rise with abrupt faces above the river flat, and slope upward toward the base of the mountain at an angle of 2–4°. They have plane surfaces and uniform slopes, and, although deeply cut by erosion, are evidently remnants of a plain which sloped somewhat continuously from the base of the mountains on either side of the valley to an axial trough somewhere near the middle of the valley.

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[1] These bowlders were found by Mr. L. F. Westgate, before the writers visited this side of the valley.

In constitution these terraces are composed of well-rounded, water-worn gravels, coarser toward the base of the mountains and up the Arkansas valley, and finer away from the mountains and down the valley. In general, the gravels in any particular place seem to correspond to the rocks found in the mountains just above. For the most part these beds are uncemented, although locally the gravels have been cemented into a friable conglomerate by lime carbonate.

Mr. Emmons, in his monograph on the Leadville district,[1] refers to the terrace deposits as being of lacustrine origin, and argues that the slope of the terraces away from the mountains is due to subsequent tilting. The correspondence in the slope of the terraces on the two sides of the valley, and the lack of any observed deformation in the beds, do not seem to favor the view that the beds have been tilted since deposition, while the coarseness and the imperfect stratification of the gravels, and the absence of any observable delta stuctures, seems to the writers to make the Lake Bed hypothesis untenable. Although locally there may have been small lakes in which deposits of gravel were laid down, by far the greatest portion of these deposits are referable to river work. With this hypothesis the slope of the terraces is in harmony. These deposits must at one time have been considerably more extensive than now, for the Arkansas River has cut a very considerable valley in the former plain of aggradation.

For the construction of the plains from which these terraces were developed there must have been a great amount of detritus supplied to the streams. In following the high terraces from the river to the mountains on either side we found in the three places which were most carefully studied, that their upper edges were in contact with bodies of older drift. The earlier glaciers, of considerably greater size than the later ones, may have supplied great quantities of débris to the swollen streams, and might well have caused the formation of the plain from which these terraces were subsequently developed by erosion. Somewhat careful search fails to show glacial striæ on the stones of the gravel, but striæ were hardly to be expected even if the gravels be of fluvio-glacial origin.

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[1] *Monograph XII*, U. S. Geological Survey, pp. 41, 71, 72.

Another fact which seems to favor the glacio-fluvial origin of these terraces is found in the relation of the Twin Lakes and Clear Creek moraines to the valley. At the time of the last glaciation the ice from the west pushed across, or nearly across, the Arkansas valley at these places, and must have blocked the valley to some extent. Now, the older drift shows that during the earlier glacial epoch the ice was even more extensive, and must also have obstructed the valley at these points. This would have given the main stream a lower gradient, if it did not dam it altogether, and so favored the deposition of the gravels above. If the valley was effectually dammed, lakes would have existed; but the main body of gravel does not appear to have been deposited while this condition existed, if it existed at all. Furthermore, it is not apparent that the dam could have been high enough at any time to hold the water up to the level of the high terraces.

That the high terraces are of great age is plainly shown by the oxidized and decayed condition of their materials, as seen in a number of fresh sections, especially about Malta. Again, the small streams from the mountains have cut valleys deep into the terraces, valleys which are much larger than those cut by similar streams in the late glacial drift.

Low terraces.—Outside of, and below, the high-terrace level there sometimes occurs a set of low terraces which bear the same relation to the last glacial moraines as the high terraces do to the older drift. They connect with the new moraines at their upper ends, and their materials are of the same lithological character as those found in the new drift. The physical condition of the material of these terraces corresponds to that of the new drift, and they have suffered an amount of erosion comparable to that which has effected the new moraines. The few available sections in the low terraces fail to show any striated stones, although plainly formed from the outwash of the new drift.

The relations of the low terraces to the new drift and of the high terraces to the older drift seem to be analogous, and point strongly to the glacio-fluvial origin of both sets of terraces.

CHANGES IN DRAINAGE AFFECTED BY GLACIATION

Two clear cases of changes in drainage due to glaciation were worked out in this region. The Eagle River, one and a half miles below Pando (Fig. 2, *a*) enters a narrow rock gorge, about three miles long. In this gorge, the stream, although of considerable size, has cut itself only a shallow valley, which is clearly very young. Just west of the point where the stream leaves its broad valley for the narrow gorge, there is a low, broad, col (Fig. 2, *b*), filled with drift, beyond which lies Homestake Creek, which has, from this point down, a much larger valley than its size would require.

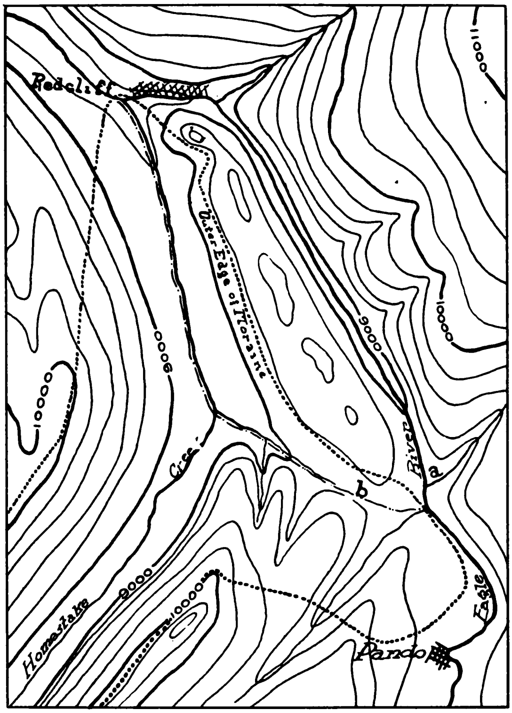

FIG. 2.—Sketch map of an area of about seventeen square miles near Pando.

a represents the head of the postglacial rock gorge entered by Eagle River a mile below Pando; *b* indicates the position of the probable preglacial course of the Eagle River. The dotted line represents the position of the moraine of the glacier which came down Homestake Creek.

The history of the change seems to be as follows: As the ice of the last glacial epoch came down the valley of Homestake Creek, it pushed across the valley then occupied by the Eagle (Fig. 2, *b*) and by obstructing the stream, ponded it, and caused it to find a new outlet to the north. On the retreat of the ice, a drift dam was left across the old valley, and the Eagle continued to occupy its new channel as far as Redcliff, where it re-enters its old valley.

The second case is that of the Arkansas River,[1] the course of which was changed by the ice of the earlier (next before last) epoch of glaciation. The ice, advancing down the valleys of Lake and Clear Creeks, pushed across the Arkansas valley to the slope on the east side, and crowded the river up against the granite walls on that side, and even shifted it up somewhat on the other slope (see Fig. 1). At these places the river cut a new channel in the rock. From data gathered from borings at the placer mines west of Granite, it appears that the surface of the rock declines to the west for a considerable distance west of Granite (Fig. 1), indicating that the preglacial channel of the river was some distance west of the present river bed between Twin Lakes and Clear Creek. The river, being pushed over to the east at two points, may have had, at first, a great loop to the west between these points. If so, the curve may have been cut out and the channel straightened by piracy, or it may have been crowded over between the ice lobes, by fluvio-glacial deposition.

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[1] Professor L. F. Westgate, of Ohio Wesleyan University, was working upon this problem when the writers entered this portion of the field, and it is understood that he will publish his results on this problem in the near future. He had worked out the essential features of the changes in the channel of the Arkansas before the writers reached this part of their field.